3RD SPACE EXPLORATION CONFERENCE & EXHIBIT

Human-Robotics Interactions:
Field Test Experiences from a collaborative ARC, JPL and JSC Team

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Main Themes

- NASA has a multi-center team that is engaging the challenges of humans working with, commanding and supervising lunar exploration robots.

- The Moon is not Mars (or the ISS):

  – Lunar architectures will need to maintain and operate equipment for long periods of time between crews.

  – Previous laboratory experiments and field tests suggest a much more interactive mode of robot operations than we have enjoyed on Mars.

  – When crews arrive, the equipment must transition to a support role, being safe, efficient and responsive to human command.

NASA's Human-Robotics Systems (HRS) Project Team

- The Human-Robotics Systems (HRS) project is managed as a part of NASA's Exploration Systems Mission Directorate's (ESMD's) Exploration Technology Development Program (ETDP).
  - Managed by the ETDP Office at Langely.
  - The HRS Project is led by JSC with a total of 7 NASA centers.
- Yes, 7 NASA centers can work together!

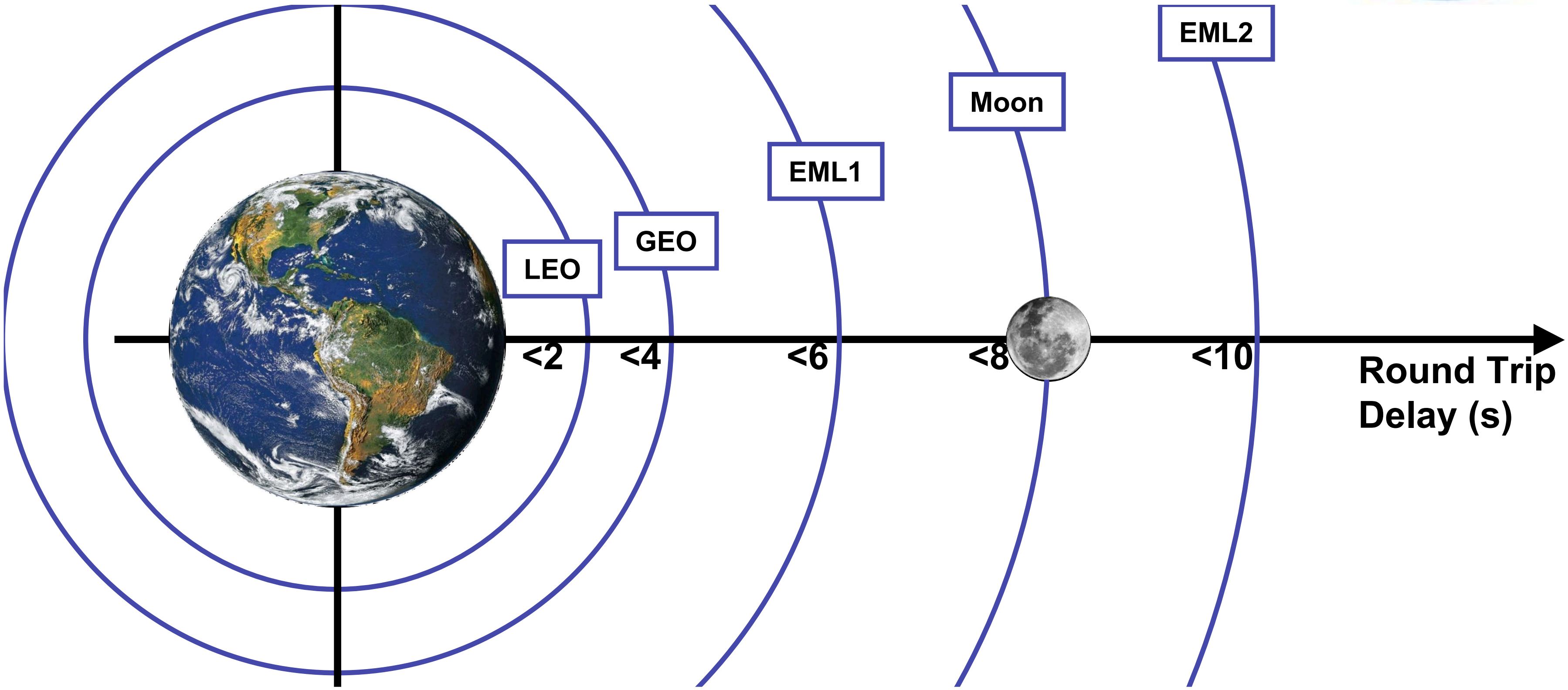
ETDPO Element Manager	Diane Hope
ETDPO Program Manager	Frank Peri

HRS Project Manager	Rob Ambrose
ARC Center Lead	Terry Fong
GRC Center Lead	John Caruso
GSFC Center Lead	Jill McGuire
JPL Center Lead	Paul Schenker
JSC Center Lead	Bill Bluethmann
KSC Center Lead	Rob Mueller
LaRC Center Lead	John Dorsey

NASA's Human-Robotics Systems (HRS) Project Work Breakdown Structure

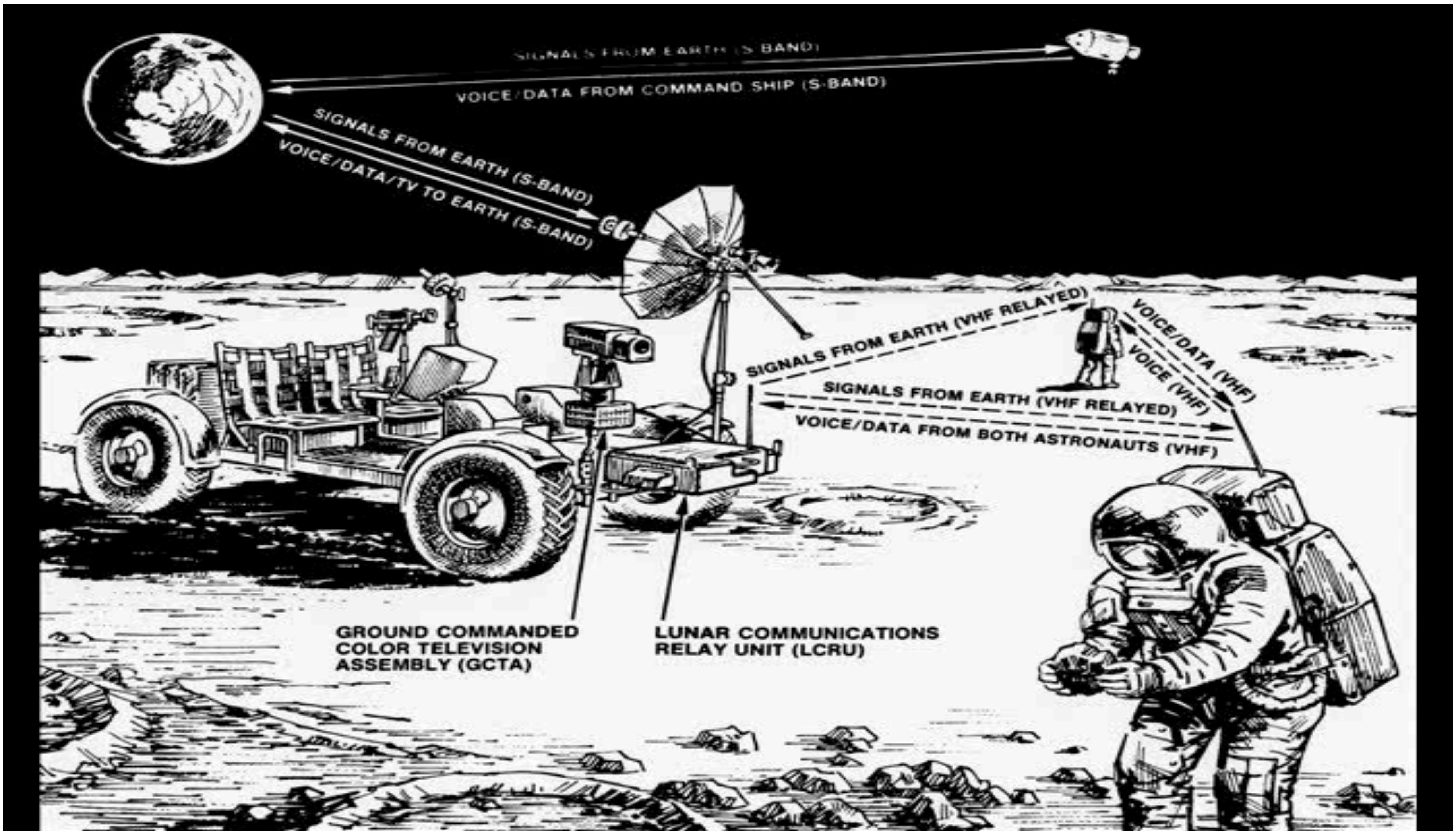
- 1.0 Management
- 2.0 Surface Mobility
  - 2.1 Vehicles
  - 2.2 Component Technologies
- 3.0 Surface Handling
  - 3.1 Large Payload Handling
  - 3.2 Small Scale Payloads & Repairs
  - 3.3 Umbilicals & Connectors
- 4.0 Human-Systems Interaction
  - 4.1 Adjacent Human (EVA) Interaction with Machines
  - 4.2 Intravehicular (IV) Command & Control
  - 4.3 Ground Supervision of Lunar Surface Systems
- 7.0 Educational Outreach

Time, Space and the Moon

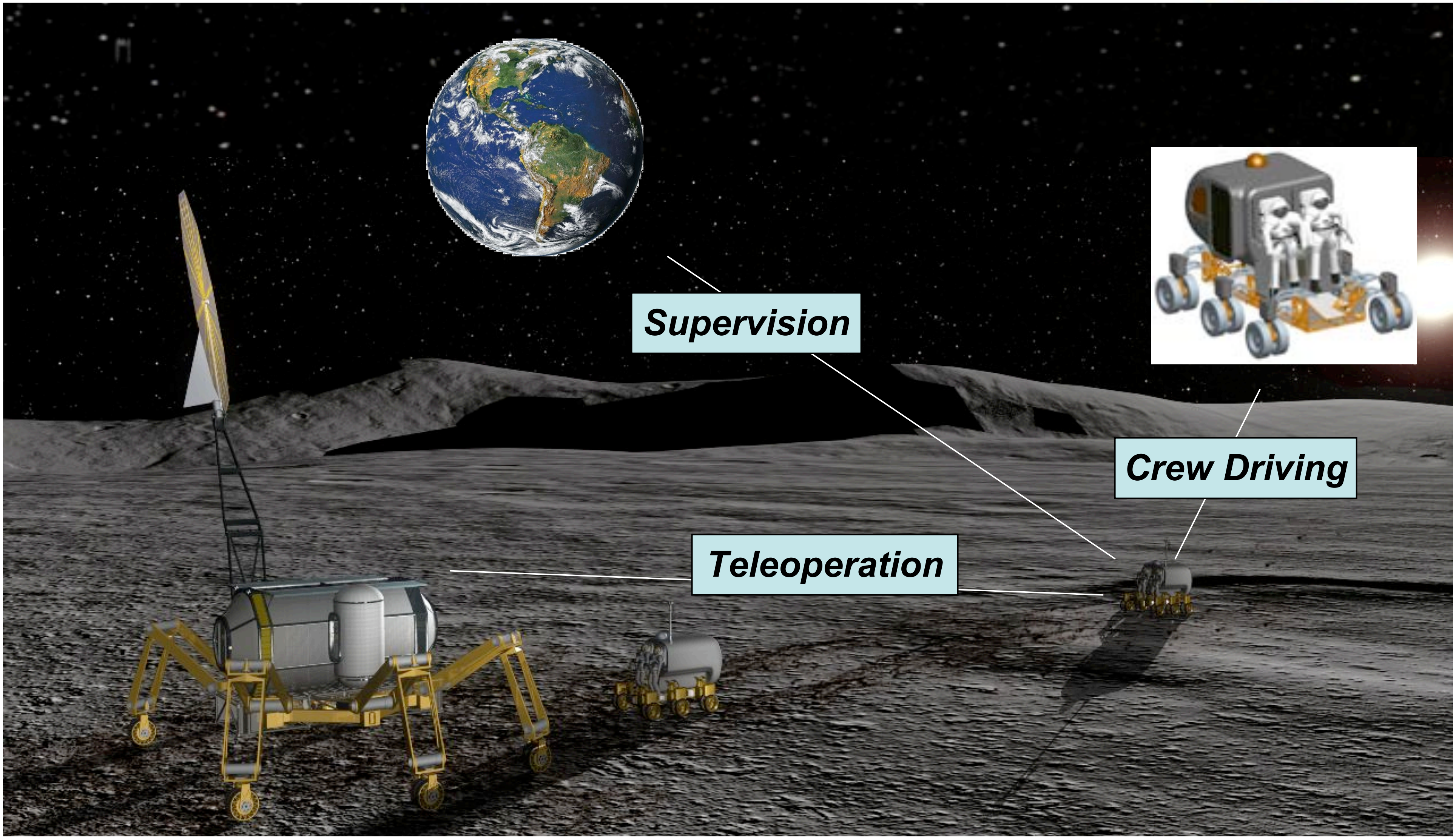


Earth to:	Distance	1 way delay Speed of Light	Round Trip Delay
LEO	400 km	0.001 sec	1-2 sec
GEO	36,000 km	0.12 sec	2-4 sec
EML1	319,000 km	1.06 sec	4-6 sec
Moon	384,000 km	1.28 sec	5-8 sec
EML2	449,000 km	1.49 sec	6-10 sec
ESL1&2	1,500,000 km	5.00 sec	12-15 sec
Mars	350,000,000km	1170.0 sec	>2400 sec

Apollo Concept of Operations



EVA, IVA and Ground Supervision



Lunar Exploration Phases

Cargo Landers

Mission Functions

Setup cameras & beacons
Setup communication net
Collect/position payloads
Connection & checkout

Robots & Crew

Mission Functions

Extend crew range
Extend crew payload
Emergency drive back
EVA worksite setup

After/Between Crews

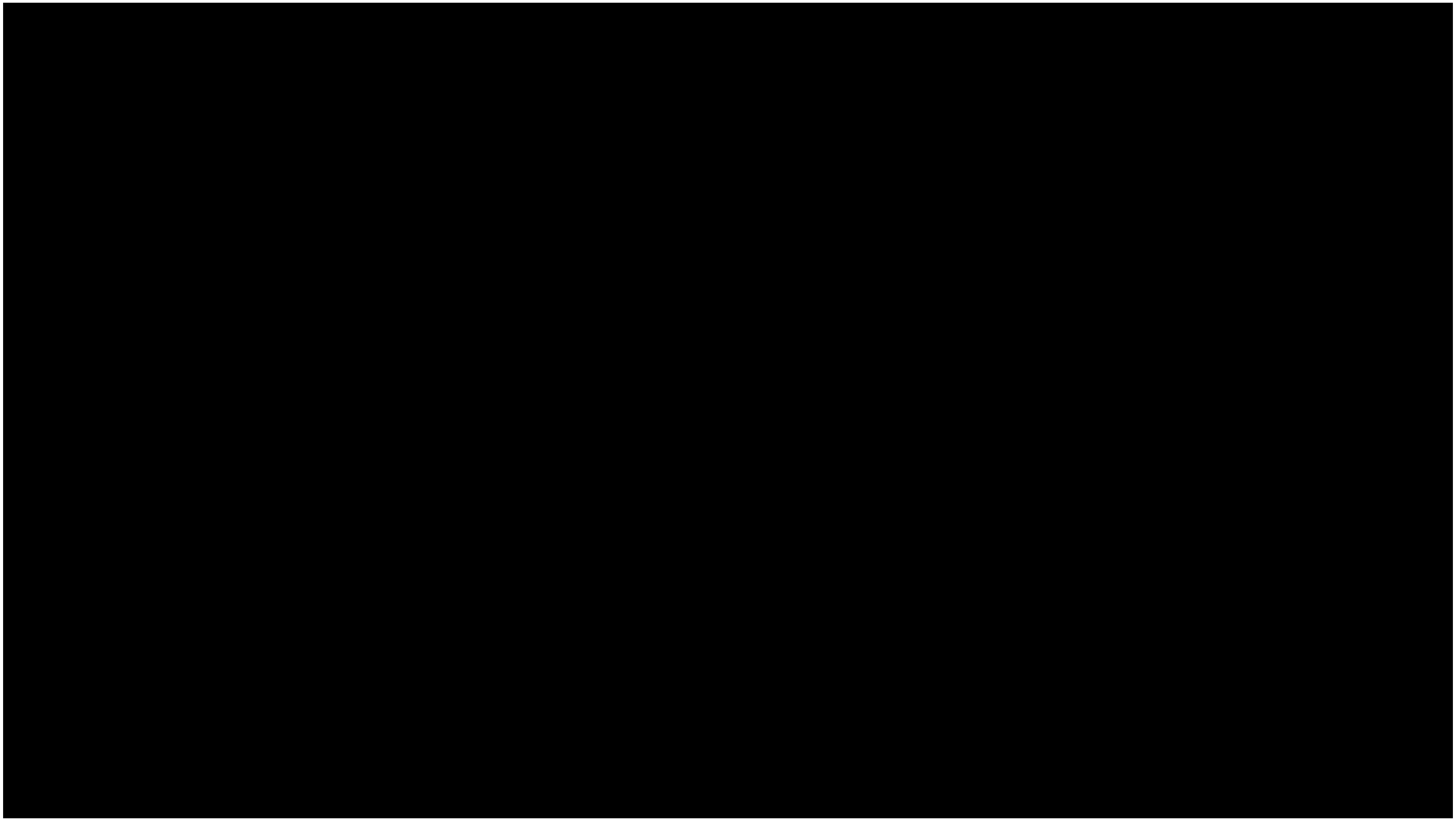
Mission Functions

Drive (un-crewed) to next site
Caretaker for facility
Load/service ISRU plant
Collect science samples

Before the Crew Arrives: Survey & Prep Site

Before the Crew Arrives: Unload Cargo

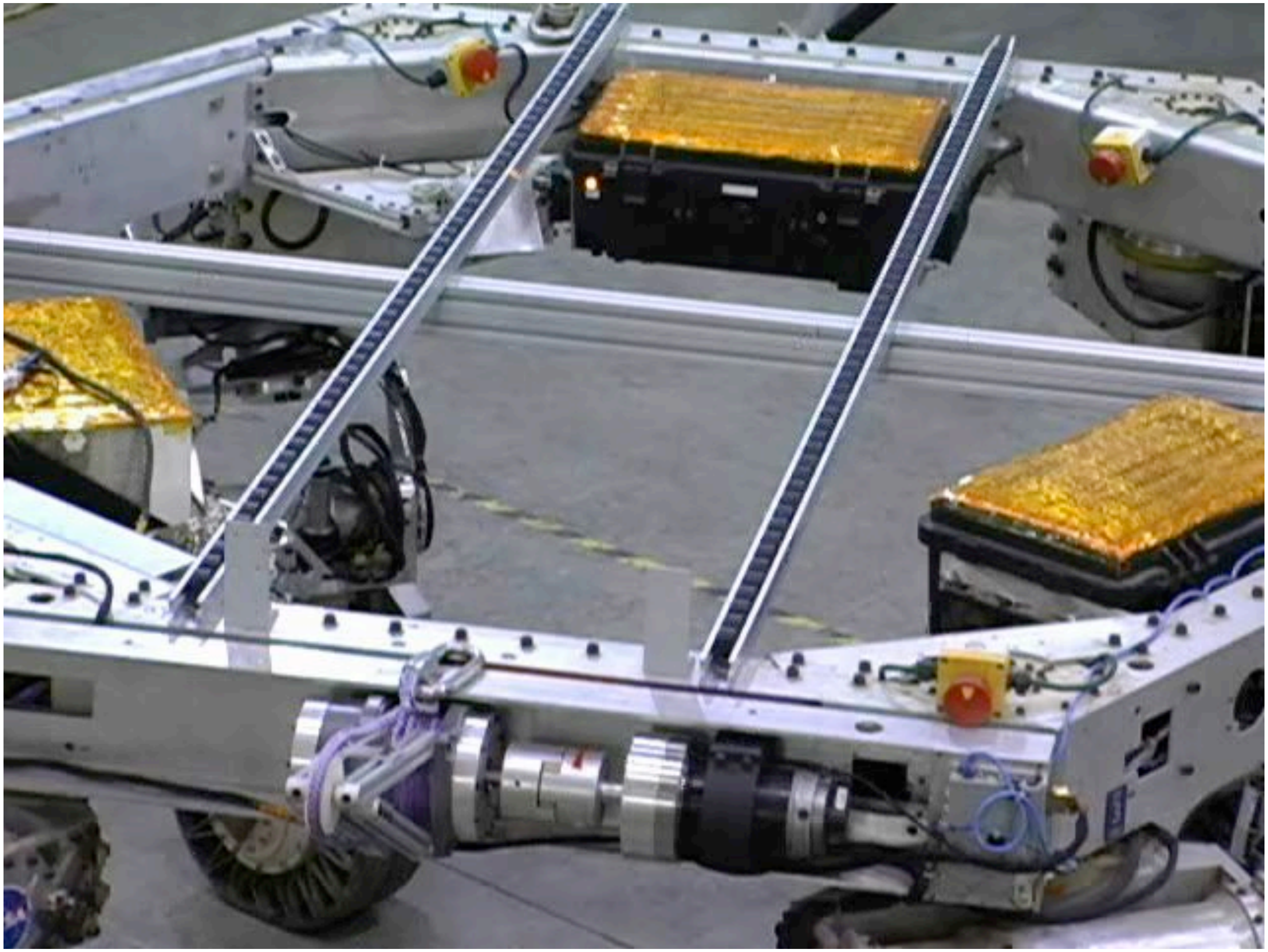
With Crew on the Surface: Exploration



Field and Lab Testing: JPL Mars Yard Testing

Field and Lab Testing: Payload Offloading

Field and Lab Testing: Payload Offloading



Field and Lab Testing: JPL Mars Yard

Field and Lab Testing: Agile Steering

Field and Lab Testing: Suit Evaluations

Field and Lab Testing: Suit Evaluations

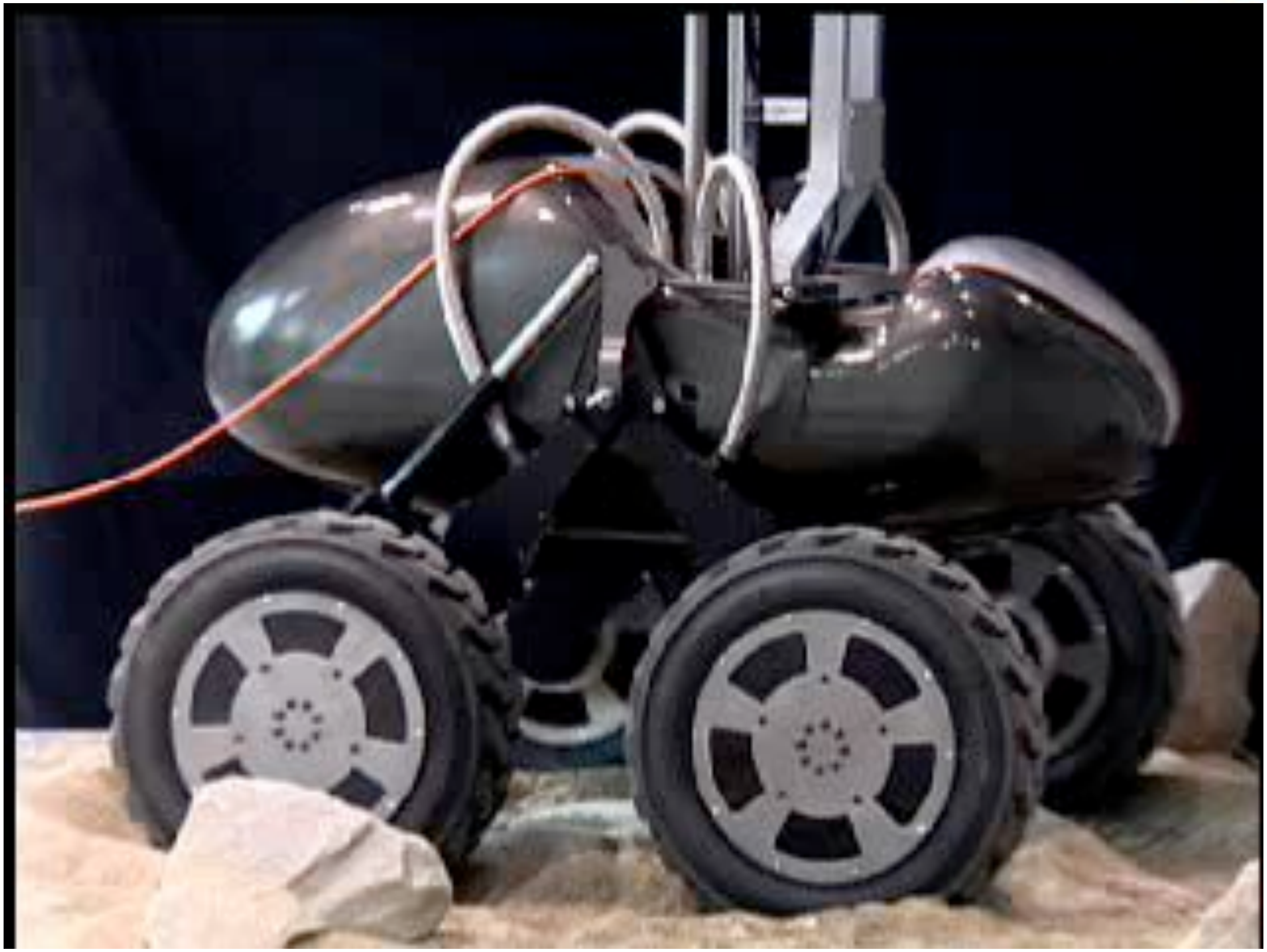
Field and Lab Testing: JSC Rockyard Craters

Field and Lab Testing: JSC Rockyard (Night)

Field and Lab Testing: JSC Rockyard (Day)

Field and Lab Testing: High Speed Driving

Field and Lab Testing: Rover Drilling



Remote Field Tests: Why do Analog Testing?

- **Architecture proof-of-concept analyses – including testing concepts in a large-scale environment**
  - **Concepts involving distances greater than that available at the JSC and JPL rock yards**
    - **Concepts requiring remote operations**
    - **Surface Operations concept analysis requiring realistic terrain**
- **Technology maturation**
  - **Demonstrating technologies that need remote operations with large scale to satisfy maturation objectives**
- **Performance of Integrated tests**
  - **Allows testing architectures and technologies in an integration fashion**
  - **Develop operational lessons learned that can be incorporated into architecture concept of operations**

Remote Field Tests: NASA's Analog Program

- Requested to Pull Together an integrated an Agency Exploration Analog Strategy that is tied to the Science Operational Concepts and the Exploration Architecture

- Outpost Science and Exploration Working Group (OSEWG) was established to drive the coordination of science and exploration
  - Work across the agency to ensure analog activities in the directorates are coordinate and can leverage off of each other to the greatest extent possible
  - Coordinate science tests with exploration system tests to the greatest extent possible

Recent Field Tests: Meteor Crater 9/2006

K-10 ARC

Meteor Crater Arizona, 9/2006

ATHLETE JPL

SCOUT JSC

Centaur JSC

Suits JSC

PRC LaRC

Recent Field Tests: Meteor Crater 9/2006

Recent Field Tests: Haughton Crater 8/2007

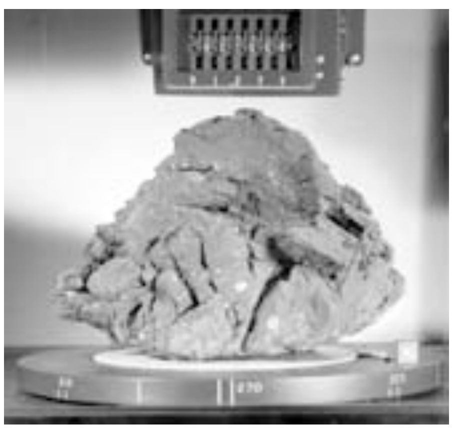
- Aligned with LAT Lander 1
  - Survey site for science
  - Survey site for construction

- Test systems in extended range and terrain
  - 30+ Km Drives
  - Soft and varied soil types
- Test Plan
  - Devon Island Canada
  - July, 2007

Recent Field Tests: Haughton Crater 8/2007

Moon

Haughton



Haughton Crater is geologically different from the Moon in many ways, but also possibly similar to the Moon in some important ways.

Key Differences:

Rock Composition

Moon: Anorthosites + Basalts

Haughton:Carbonates + Gneisses

Regolith Maturity

Moon: Mature regolith formed after intense impact/radiation processing.

Haughton: Immature regolith: Single event impact generation.

Key Similarities:

Ice-Rich Mixed Impact Rubble

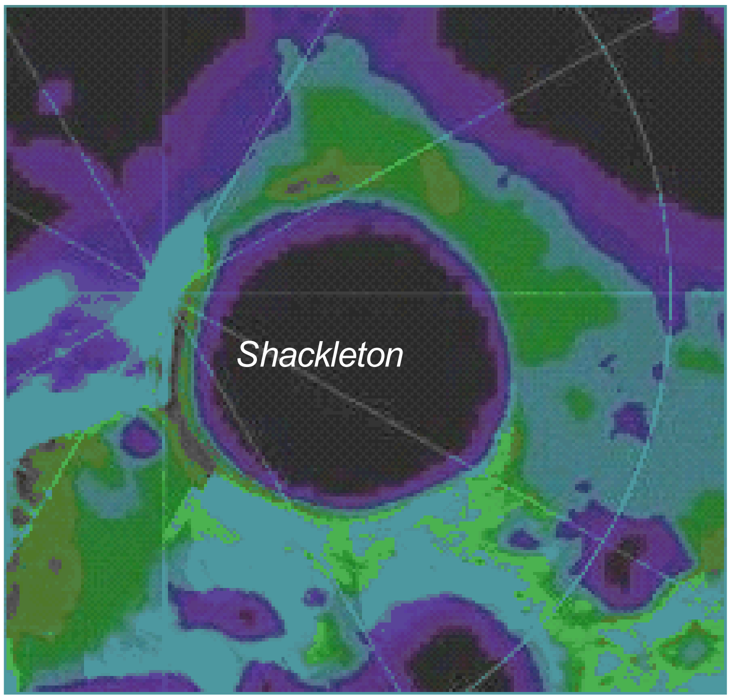
Haughton's impact breccia deposits are a polymict (multicompositional) impact rubble rich in ground ice, possibly similar in that respect to the lunar regolith in polar regions.

Ejecta Blocks and Impact Rock Fields

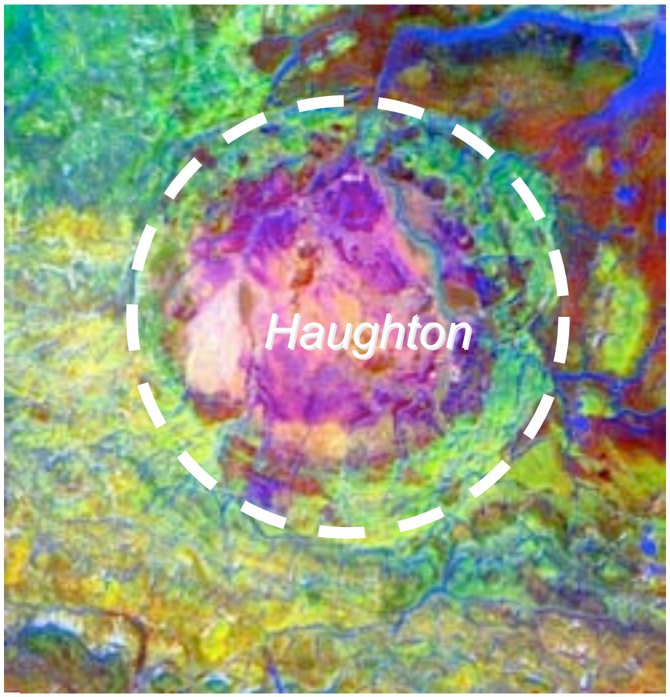
Haughton presents ejecta blocks and impact rock (impactite) fields that offer petrologic and operational similarities with impact processed materials and terrains on Moon.

Recent Field Tests: Haughton Crater 8/2007

Shackleton Crater at the South Pole of the Moon is 19 km in diameter and might present H_2O ice in surrounding shadowed zones. It is a prime candidate site for human exploration. Haughton Crater, also ~ 20 km in size, is by far the best preserved impact structure of its class on Earth and is located in a H_2O ground ice–rich rocky desert. Haughton may be the best overall ***scientific and operational analog for lunar craters such as Shackleton***.



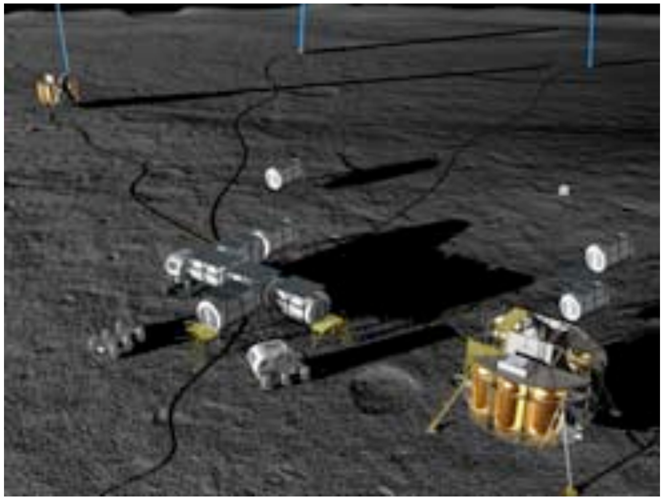
Map of 19 km Shackleton Crater at lunar South Pole.



ASTER image of 20 km Haughton Crater, Devon Island, High Arctic.

Recent Field Tests: Moses Lake 6/2008

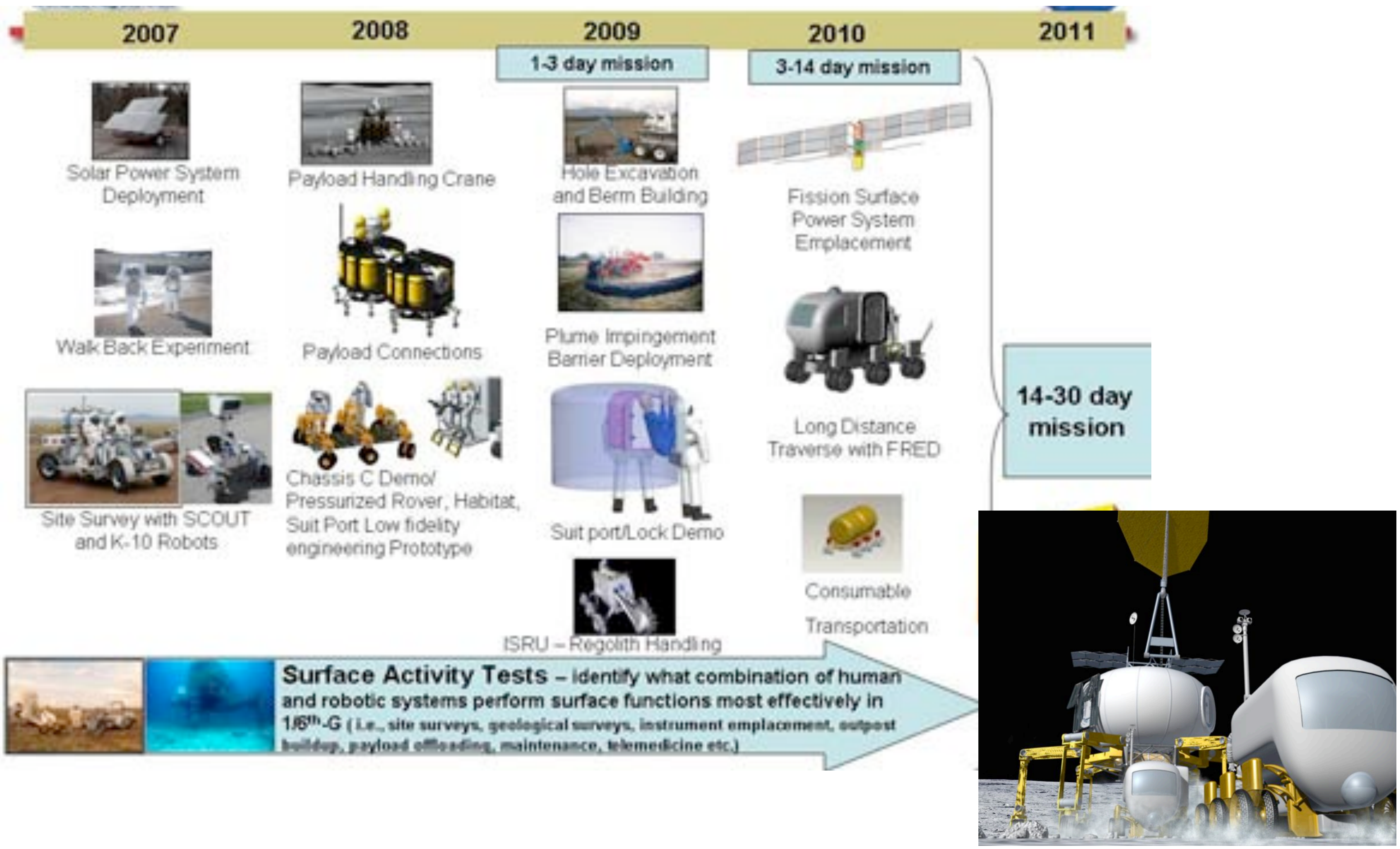
- Aligned with LAT Landers 1,2,3 and 6
  - Deploy small to medium sized payloads with crane.
  - Position rovers and habitats prior to Crew arrival
  - Support expanded crew exploration
  - Reconfigure assets awaiting next crew
- Test systems in extended range and terrain
  - 1 Km Drives
  - Soft and varied soil types
- Test Plan
  - Moses Lake Wa
  - June 1-13, 2008



Recent Field Tests: Desert Rats 10/2008

- Aligned with LAT Landers 4 and 5
  - Deploy small pressurized rover (SPR)
  - Combine SPR with ATHLETE based mobile habitat
  - Support expanded crew exploration
- Test systems in extended range and terrain
  - 10 Km Drives
  - 1-3 Day Overnight Excursions
- Test Plan
  - Site is TBD
  - Late October, 2008

Recent Field Tests: Out Year Plan



Conclusions

- NASA Centers can Work Together!
  - ETDP-HRS Project underway
  - 7 Centers, 2 universities, 100+ vendors

- NASA Analog program testing ideas & systems
  - Combined with Lab and Rockyard Testing
  - Aligned with ESMD architecture

- Field Tests On Deck
  - June HRS Test
  - October Desert Rats